NATIONAL RADIO ASTRONOMY OBSERVATORY

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1 April 2015

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Amendment of Parts 1, 2, 15, 90 and 95 of the Commission's Rules to Permit Radar Services in the 76-81 GHz Band	)	ET Docket No. 15-26
	)	
Amendment of Part 15 of the Commission's Rules to Permit the Operation of Vehicular Radar Services in the 77-78 GHz Band	)	RM-11666
	)	
Amendment of Sections 15.35 and 15.253 of the Commission's Rules Regarding Operation of Radar Systems in the 76-77 GHz Band	)	ET Docket No. 11-90 RM-11555
	)	
Amendment of Section 15.253 of the Commission's Rules to Permit Fixed Use of Radar in the 76-77 GHz Band	)	ET Docket No. 10-28
	)	
Amendment of the Commission's Rules to Permit Radiolocation Operations in the 78-81 GHz Band	)	WT Docket No. 11-202

Comments on the NOTICE OF PROPOSED RULEMAKING AND RECONSIDERATION ORDER 15-16

by

National Radio Astronomy Observatory

I. Introduction

1. Here, the National Radio Astronomy Observatory ("NRAO" or "the Observatory") comments on the Federal Communications Commission's Notice of Proposed Rulemaking and Reconsideration Order ("the NPRM") 15-16 regarding uses of the 76 – 81 GHz band for vehicular and other radiolocation/radar applications.

2. NRAO (http://www.nrao.edu) is the largest observatory dedicated to radio astronomy and one of the largest astronomical observatories in the world. NRAO operates the 10-antenna Very Long Baseline Array (VLBA) and the 100 m Robert C. Byrd Green Bank Telescope (GBT) which observe at mm-wave frequencies and stand to be

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affected by the Commission's actions in this matter. NRAO pioneered the use of mm-wave spectrum for radio astronomy in 1968 at its 36' Kitt Peak antenna, whose site is currently occupied by a new Arizona Radio Observatory (ARO) 12m telescope, see http://aro.as.arizona.edu/.

3. The mm-wave spectrum is unique in the access it affords to molecular spectra that form the basis of the burgeoning field of astrochemistry. Shown in Figure 1 is a very condensed version of a wideband spectral survey toward a star-forming region in Orion recently conducted at the GBT[1]. Scatter at the base of the strong and sharp spectral features is not so much noise as a welter of weak lines. Hundreds of molecules (including isotopologues and conformers) are represented in the Figure.

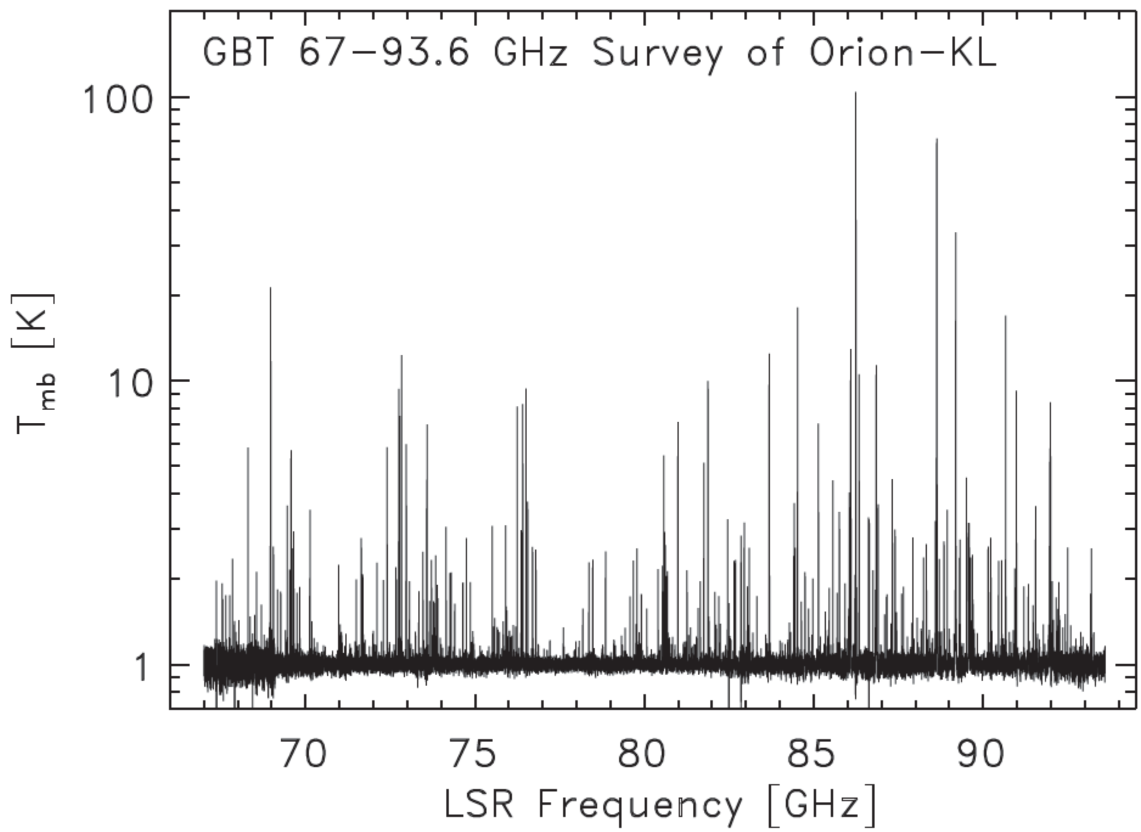


Figure 1: The 67 – 93.6 GHz spectrum of Orion as seen at the GBT

II. Addressing the Commission's requests for specific comments

4. As noted in the NPRM at ¶34, an empirical test[2] was conducted in which car radar representatives from Bosch and Continental and radio astronomy representatives from NRAO, Haystack Radio Observatory and the University of Arizona, working under the auspices of the National Science Foundation, collaborated to measure the emissions from vehicular radar systems as received at the former ARO 12m telescope on Kitt Peak.

[1] Available at http://arxiv.org/abs/1502.01280
[2] http://www.gb.nrao.edu/electronis/edtn/edtn219.pdf

5. In discussing this study at ¶34 the Commission posed a generalized set of questions which we quote and enumerate as follows to be addressed at the conclusion of our own discussion: "We therefore seek comment on the conclusions of the study **(a)** and how the results of the study would impact a proposal to adopt technical requirements for the entire 76-81 GHz band similar to the existing vehicular radars operating in 76-77 GHz band **(b)**. How can mitigation factors be used to reduce interference to radio observatories **(c)**? We invite interested parties to comment on the potential for such interference **(d)**. In particular, we invite interested parties who believe that the NSF study does not accurately describe the potential for such interference to submit evidence in the record sufficient to support their arguments **(e)**. We also seek comment on whether the potential for interference resulting from vehicular radars in the 76-77 GHz band is likely to be similar to or different from the potential for such interference in the entire 76-81 GHz band **(f)**. Finally, we seek comment on whether the mitigation factors identified in the study should be implemented for vehicular radars **(g).**

III. The Kitt Peak Study

6. It is of the utmost importance to understand the circumstances of the Kitt Peak test and what it actually did and did not accomplish. Although a radar-equipped vehicle was originally sought for the study, the actual radar devices under test were mounted outboard on a vehicle located slightly above the telescope in a Kitt Peak National Observatory parking lot at a distance of 1.7 km and on the runway of a small airport lower in elevation at a distance of 27 km. During the test, the optical path of the telescope was diverted toward the radar, the gains and losses of the receiving system were established and the eirp of the emitting test devices, 9 – 11 dBm as specified by the manufacturers, were accurately measured.

7. At the most basic level the Kitt Peak test accomplished little more than to calibrate the optical path of the ad hoc test arrangement but it did serve to show two things:

   i) The appropriate atmospheric attenuation around 79 GHz in the vicinity of a typical RAS site is 0.15 dB/km [3], providing scant protection at radio observatories that were specifically selected to maximize atmospheric transmission. This is somewhat in contradiction to common assertions that mm-wave frequencies are of especially short range, eg in the NPRM at ¶4 and ¶31 and footnote 79.

   ii) The radar signals were detected fully: That is, there is nothing in the nature of the radar emission or the radio astronomy receiving chain that affords immunity from interference to radio astronomy by the radar.

8. Well after the Kitt Peak test, the typical operating characteristics of 76 – 77 and 77 – 81 GHz vehicular radars were published in ITU-R Recommendation M. 2057 ("M. 2057") in preparation for compatibility analyses to be conducted under WRC-15

[3] This was subsequently re-derived and incorporated in compatibility analyses at the ITU-R in preparation for consideration of WRC-15 Agenda Item 1.18.

Agenda Item 1.18[4]. Perhaps somewhat surprisingly, Table 1 of M.2057 states that, in an operating (bumper-mounted) car radar system, 10 dBm (the power level of the devices under test at Kitt Peak) is the input power to an outgoing antenna whose gain for a typical 77 – 81 GHz short range radar (SRR) is 23 dB, producing an operating eirp of 33 dBm. Thus the Kitt Peak test was conducted with radar devices whose eirp were about 23 dB or 200 times smaller than that of an operating car radar. The eirp of 76 – 77 GHz long range radar (LRR) are higher still, 50 dBm according to M. 2057.

9. The participants in the Kitt Peak report compared the eirp of the tested "short-range radar" devices (ie 9 – 11 dBm) with the threshold for detrimental interference given in ITU-R Recommendation RA. 769 ("RA. 769") and calculated that a nominal line of sight separation distance (described as an "avoidance radius") of some 30 - 40 km (including atmospheric attenuation) would be needed to prevent interference from a single device. The derived size of the avoidance zone was not really dependent on the actual test measurement, which merely confirmed that the eirp of the devices under test were equal to the values on the manufacturers' spec sheets. The same size of an avoidance zone could have been calculated from first principles using the test sheets before the test. And in no way did the discussion recognize that the devices under test were so much weaker than actual operating SRR would have been, or indeed that administrations which had already authorized radars across the 76 – 81 GHz band had done so at power levels 50 dBm as given in ITU-R Recommendation M. 1452 ("M. 1452").

10. In discussing the calculated size of the avoidance zone on p. 12 of the Kitt Peak test report, the study participants stated what seemed to be obvious at the time, namely "Mitigation factors such as any terrain shielding, orientation of the transmitter antenna with respect to the observatory, or attenuation of the transmitter if mounted behind the vehicle bumper have not been taken into account, and would tend to reduce the avoidance radius." In retrospect, this statement is misleading. If mounted behind a bumper the outgoing radar eirp would have been 23 dB stronger according to M. 2057 or 35 dB stronger according to M. 1452 and this was the major factor that was not taken into account in the test.

IV. Separation distances and aggregation

11. Vehicular radars are projected to proliferate much as airbags did. At first, few cars had even one airbag but now all cars have several. Thus, the typical vehicle in a few years will have LRR facing forward and SRR ringing the car (eg NPRM at ¶6 and 26). The horizontal orientation of a car on the ground will mainly affect which radar is visible.

12. As described in M. 2057, the half-power points of a SRR radar beam in the vertical plane are at +/- 5.5°. Taking the example of the Kitt Peak 12m telescope that is some 700 m above the surrounding terrain, the telescope will fall vertically within the half-power radar beam at horizontal distances (ie from the car to the base of the mountain) greater than 0.7 km/tan 5.5° = 7.3 km or about 4.5 miles. The KP antenna will be

[4] M 2057 contains much more information about the characteristics of 76 – 81 GHz radars than has previously been placed into the public record of the Commission's car radar proceedings.

illuminated at nearly full strength by most of the radars that are visible to it from the surroundings below. 76 – 77 GHz LRR have a narrower HPBW, +/- 3° according to M. 2057.

13. Thus, vehicle radars tend to illuminate diverse objects, including telescopes, with very nearly the same eirp at which they operate. At the 50 dBm eirp that is proposed in the NPRM, the nominal line of sight separation distance is 190 km (or 109 km for eirp of 33 dBm), where we use the threshold power flux density -125 dB W/m^2 for continuum observations in Table 1 of RA. 769 (because the radar emission is broadband) and the atmospheric attenuation of 0.15 dB/km. These distances are much longer than those noted in the Kitt Peak study owing to the higher eirp levels.

14. The separation distances will increase when radar emissions aggregate from multiple vehicles. In a large metropolitan area literally millions of radars could be operating at peak traffic times. The observatory has estimated, crudely, that of order 10 vehicles are in view of the GBT on local roads during daylight hours on weekdays.

V. Ground Clutter, terrain shielding and ring-fencing

15. Despite the extreme isolation that the Commission has attributed to US mm-wave radio telescopes as a basis for denying them protection from other uses of mm-wave radars (eg the Level Probing Radar Report and Order and Order 14-2 in ET Docket 10-23 at ¶60) they are often quite exposed over at least some part of the horizon. The GBT is visible from the local roads as shown in Figure 2. The Kitt Peak 12m is visible from the surrounding lower terrain for many miles as the result of its elevation, and from the public road and parking lots at higher elevations within Kitt Peak National Observatory as shown in Figure 3. At night one sees car headlamps moving about on lower terrain from a typical mountain observatory so mm-wave radar signals would also impinge.

16. NRAO has considered what would be required to erect an electromagnetic barrier around an exposed mm-wave antenna and concluded that fencing is grossly infeasible. Structures that simultaneously allow antennas to point down to suitably low elevations (we considered 12°) while being high enough to intercept incoming radar signals without diffracting them onto the telescope would be monumental constructions even for modest dishes. To protect a 12m antenna against a single oncoming LRR on level ground would require a fence 70 m high at a distance of 320 m from the antenna. At mm-wavelengths a protective structure must be nearly solid owing to the short wavelengths, rendering it susceptible to the harsh conditions of wind and weather that occasionally occur at typical radio astronomy sites.

Figure 2: The 100 m Robert C. Byrd Green Bank Telescope (GBT) as seen looking south on Rt. 28/92 in weather that is definitely not suitable for mm-wave observing

17. We conclude that when naturally occurring terrain shielding is not available, it cannot be created artificially. Radio astronomy telescopes are, as the Commission has stated, in remote locations. But when this does not fully protect them, they must be granted the regulatory protections that are always available to protect incumbent operations.

VI. Unwanted emissions limits

18. At 95.1617 b (3) of the proposed rules one reads “For field disturbance sensors and radar systems operating in the 76-81 GHz band, the spectrum shall be investigated up to 231.0 GHz.” The Observatory believes this is holdover language from when the text in question applied to the band 76 – 77 GHz (3x77 GHz = 231 GHz) and that the correct value now is 3x81 GHz = 243 GHz. It is important that this be correct because the spectrum at 226 – 231.5 GHz is a passive service band protected by US246.

19. The proposed unwanted emissions limits specified by the Commission in 95.1617 b (2), equivalent to -31.7 dB W/MHz and -29.5 dBW/MHz at 40 – 200 GHz and above 200 GHz respectively, are unphysical and grossly lax. Consider the primary emission standard proposed for SRR at 77 – 81 GHz, 50 dBm over 4 GHz or an average eirp density of -16 dB W/MHz: The unwanted emission levels proposed for SRR are only about 15 dB below that level of wanted emissions. With this standard, car radars would be allowed to radiate nearly equal power in wanted and unwanted emission up

to the upper limit of measurement of the latter. The level of unwanted emissions should not be allowed to grow with frequency separation from the operating band.

Figure 3. The ARO 12m telescope (left, in dome) and 25m NRAO VLBA antenna on Kitt Peak as viewed from above within Kitt Peak National Observatory.

20. Consider these unwanted emission limits of -30 dB W/MHz with respect to radio astronomy operations in the adjacent bands above 81 GHz, where the protection criterion for broadband continuum observation (RA. 769 Table 1) is -222 dB $W/m^2/Hz$ = -162 $dBW/m^2/MHz$. This implies a separation distance of 120 km including atmospheric attenuation of 0.15 dB/km. *For unwanted emissions.*

21. The third harmonic of radars operating at 76 – 81 GHz occurs at 228 – 243 GHz, overlapping the passive service band at 226 – 231.5 GHz that is protected by US 246. Unwanted emissions from car radar could render this band useless to passive services unless appropriate unwanted emissions limits are in place. There are no formal protection criteria in RA 769 for the level of unwanted emissions that fall into passive service bands but the proposed unwanted emissions standards would imply very large separation distances for a hypothetical shared radio astronomy band at 226 – 231.5 GHz. In that band the atmospheric attenuation in the vicinity of a radio astronomy site, calculated by the Observatory, is 0.33 dB/km.

22. The Commission might wish to consider that the limits it proposes for unwanted emissions exceed by 30 – 32 dB the standards under which such radars are manufactured in Europe by petitioner Bosch. These are given for 76 – 77 GHz LRR in ETSI EN 301 091-1 as -30 dBm/MHz at frequencies of 1 – 300 GHz and for 77 – 81 GHz SRR in document ETSI EN 302 264-1 as -30 dBm/MHz at frequencies of 1 – 100 GHz.

23. Car radar unwanted emissions therefore should and can be limited to far lower levels than those that are proposed by the Commission, and should be more strongly confined in frequency. The permitted level of unwanted emissions should not be allowed to rise above 200 GHz.

VII. Damage to radio astronomy receivers from mm-wave radar

24. The 10 dBm total power emitted by one SRR or LRR is just below the 25 mW input power that will destroy a radio astronomy receiver according to ITU-R Report RA. 2188. Permanent damage will occur at lower levels that are harder to ascertain precisely according to RA. 2188. For a LRR with a beam (half-power beamwidth) of 6° (M. 2057), a telescope of diameter D fills the beam at distances d = 9.55 D where the numeric constant is the ratio of 1 radian to 6°. For a 12m antenna this is 115 m, or for the GBT (whose surface is actually 110 m in the horizontal direction), 1 km.

25. Although it may seem unlikely that car radars will point near the boresight of a radio astronomy antenna, these antennas are commonly visible from roads on higher ground, as witnessed by the Kitt Peak study that stationed the radar in a parking lot above the telescope during one phase of the test, and as shown in Figure 3 here.

VIII. Addressing the Commission's requests for specific comments

26. Here NRAO addresses the Commission's requests for comments as enumerated at ¶5:

   a) The study showed that radio astronomy receivers readily detect car radar emissions and that the atmospheric attenuation is modest in the vicinity of a telescope observing in the 79 GHz band. The conclusions of the study[5] were that single so-called "short-range radars" with eirp near 10 dBm would require zones of avoidance of 30-40 km for telescopes in direct line of sight, or smaller zones under other conditions that were mentioned notionally as possibilities, and in the case of bumper loss, rather misleadingly.
   b) The study suggests that the interference from LRR and SRR will differ mainly in how much aggregate energy is emitted by each type of radar. Aggregation

[5] "10 Conclusions Tests performed with short range vehicular radar systems, operated at distances of 1.7 km and 26.9 km from the University of Arizona's 12 Meter millimeter wave telescope, demonstrated that these radars could have a significant impact upon radio astronomy observations in the 77 to 81 GHz region. A zone of avoidance of about 30 to 40 km around a mm-wave observatory would be needed, in order to keep interference from a single vehicle below the threshold defined in RA.769-2. Smaller zones of avoidance might suffice in areas without direct line of sight to the radio telescope and/or by taking some of the above mentioned mitigation factors into account. ITU-R RA.1272-1 specifically recommends that such zones be established around mm-wave astronomical observatories, following the procedure outlined in Recommendation ITU-R RA.1031-2"

of interferers, operation of individual radars at levels 40 dB higher than employed in the Kitt Peak study, and the presence of multiple radars per vehicle act to magnify interference concerns to an extent that the study did not envision and to which its results cannot be directly extrapolated.

c) Mitigation factors suitable for the protection of incumbent radio astronomy operations remain to be defined quantitatively, based on realistic deployment scenarios and local astronomy operating conditions. Examples of measures that should be taken to protect radio astronomy are given in Section IX here.

d) Individual vehicular radars cannot operate at the proposed eirp in direct line of sight of a radio telescope without causing interference far above the threshold levels in RA. 769. At the proposed unwanted emission levels there will be substantial interference in adjacent and higher-lying radio astronomy bands, including passive service bands protected by US246.

e) The Kitt Peak test referred to individual devices having eirp 40 dB below the Commission's proposed operating levels. Cars will be ringed by multiple radars and will operate within line of sight in substantial numbers.

f) Interference at 76 – 77 GHz will differ from that at 77 – 81 GHz in scale, depending on how much aggregate power or power density is emitted in each band.

g) In discussing the calculated size of the avoidance zone on p. 12 of the Kitt Peak test report, the study participants stated what seemed to be obvious at the time, namely "Mitigation factors such as any terrain shielding, orientation of the transmitter antenna with respect to the observatory, or attenuation of the transmitter if mounted behind the vehicle bumper have not been taken into account, and would tend to reduce the avoidance radius." In retrospect, this statement is misleading. If mounted behind a bumper the outgoing radar signal would have been 23 dB stronger according to M. 2057 and this was the major factor that was not taken into account in the test. The horizontal orientation of a fully radar-equipped vehicle will matter little and the interference reaching a telescope will have been emitted in an upward direction that is not susceptible to shielding by ground clutter. The only mitigation factor discussed in the study that is not entirely accidental in nature (ground clutter) or inappropriate (placement behind the bumper) would be avoidance zones.

IX. Measures to protect radio astronomy operations from vehicular radars

27. An operator-controlled radar off/on-switch, to allow vehicles to circulate safely in the vicinity of mm-wave telescopes where there is a potential for very strong interference and outright destruction of a radio astronomy receiver. Headlights have off/on-switches; seatbelts must be attached manually and do not have ignition interlocks. Cars must be safely operable without radars. Indeed, 76 – 77 GHz long-range radar for collision avoidance and adaptive cruise control is now described in M. 2057 as providing only "additional comfort functions," whatever that might mean.

28. Location-based coordination zones. MM-wave radars must absolutely be prevented from operating within some distance of radio telescopes that is perhaps a small multiple of the distances calculated in Section VII, ie one to several km, in order to

prevent outright destruction of a radio astronomy receiver. Larger coordination zones will be needed to prevent interference to incumbent radio astronomy operations but these must be based on realistic deployment scenarios under local conditions.

29. Car radar unwanted emissions should at least be limited to the eirp density levels -30 dBm/MHz given by the ETSI standards under which the devices are manufactured in Europe by petitioner/vendor Bosch.

30. Unwanted emissions should be more strongly confined in frequency than proposed by the Commission and should not be allowed to rise above 200 GHz. There should be strict limits on unwanted emissions into the passive service bands at 148.5 – 151.5 GHz and 226 – 231.5 GHz at or very near the 2^{nd} and 3^{rd} radar harmonics.

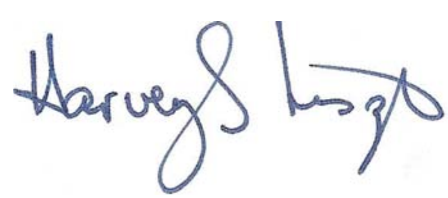
31. When extending the car radar operating band from 76 – 77 GHz to 76 – 81 GHz, the upper frequency limit of investigation of unwanted emissions should be extended to cover the full 3^{rd} harmonic of the newly expanded band, ie to 243 GHz = 3 x 81 GHz, from the existing and proposed value 231 GHz = 3 x 77 GHz.

32. Primary status should be provided for radio astronomy across the full band 76 – 81 GHz.

X. Use on aircraft

33. As with FOD, there are no obvious examples of US mm-wave radio astronomy sites that would be affected by surface use of wingtip radar at airports but use of mm-wave radar in flight at any but the very lowest elevations could be exceptionally harmful given the impossibility of shielding and the great range of visibility of aircraft in flight. ECC Report 222[6] gives vivid examples of the possibilities for interference to European radio astronomy operations when mm-wave radar is used on helicopters while inflight.

Respectfully submitted,
National Radio Astronomy Observatory



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